

RHIC-PG-52

Electron Trappings
in RHIC
from a Debunched Proton Beam

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Ion Trapping / Electron Trapping

Proton Beam Completely Debunched

Gas Composition as derived in RHIC-PG-51

Densities:

| Molecules | <u>Z</u> | <u>A</u> | <u>warm</u> | <u>cold</u> |
|----------------|----------|----------|-----------------------------------|-----------------------------------|
| H ₂ | 2 | 2 | $2.1 \times 10^7 \text{ cm}^{-3}$ | $2.3 \times 10^7 \text{ cm}^{-3}$ |
| He | 2 | 4 | - | $2.3 \times 10^7 \text{ cm}^{-3}$ |
| CO | 14 | 28 | $2.1 \times 10^7 \text{ cm}^{-3}$ | - |

Ionization cross-section σ_i

$$\sigma_i = 1.8 \times 10^{-19} Z_i \text{ cm}^2$$

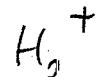
Ionization Rate for He with specie per proton

$$\frac{dn_i}{dt} = c \sigma_i n_i \quad (\beta = 1)$$

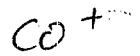
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ions

ionization rate

0.243 s⁻¹ / proton

0.186



0.397

electrons0.826 s⁻¹ / proton

The ions (positively charged) are rejected by the potential barrier of the proton beam.

The electrons could be trapped.

Average energy of the electrons at production

$$\frac{1}{40} \text{ eV}$$

which corresponds to a velocity

$$v_e \approx 10^7 \text{ cm/sec}$$

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To "clear" the electrons one can create one or several gaps in the beam - These gaps though are to be no less than 300 ~~usec~~
usec if the electrons have to reach a wall 3 cm away with the velocity given above.

Assume the proton beam has a uniform density distribution with elliptical cross-sections of semi-axes δ_x, δ_z

$$I_{\text{beam current}} = N e f_{\text{rev.}} = 57 \times 10^{12} \times 1.6 \times 10^{-19} \times 78.2 \times 10^3$$

$$= 0.71 \text{ Ampere}$$

Electric Field produced by the beam

$$E_{x,z} = \frac{(120 \text{ ohm}) I_{\text{amp}}}{\delta_x + \delta_z} \frac{(x, z)}{\delta_{x,z}} \text{ Volt/m}$$

The voltage distribution is

$$V = \frac{43 \text{ Volt}}{\delta_x + \delta_z} \left(\frac{x^2}{\delta_x^2} + \frac{z^2}{\delta_z^2} \right)$$

The potential barrier depth is calculated by setting $x = \alpha_x$ and $\epsilon = \alpha_z$, and that is

$$\boxed{\Delta V = 43 \text{ Volts}}$$

Oscillation Frequency of the Trapped Electrons.

$$\omega_{x,z}^2 = \frac{(120 \text{ ohm}) I e c^2}{m_e c^2 \alpha_{x,z} (\alpha_x + \alpha_z)}$$

where $m_e c^2 = 0.5 \text{ MeV}$ and $\alpha_{x,z}$ is in meter.

$$\alpha_{x,z} (\alpha_x + \alpha_z) \approx 20^2, \quad \alpha \approx 4 \text{ mm}$$

As a result

$$\boxed{\omega_{x,z} \approx 700 \text{ MHz}}$$

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Betatron Time Depression

$$\Delta v_{x,z} = \frac{e}{4\pi m \beta^2 c^2} \int ds \beta_{x,z}(s) \frac{\partial E_{x,z}^{(s)}(s)}{\partial x,z}$$

$E_{x,z}^{(s)}$ is the electric field generated by the electrons in the background.

$$\frac{\partial E_{x,z}}{\partial x,z} = \gamma \frac{(120 \text{ ohm}) I}{\sigma_{x,z} (\sigma_x + \sigma_z)} = \frac{86 \Omega}{\sigma_{x,z} (\sigma_x + \sigma_z)}$$

γ , charge neutralization coefficient caused by the electrons.

We have

$$\Delta v_{x,z} = \frac{120 e I}{4\pi m \beta^2 c^2} \int \frac{\gamma(s) \beta_{x,z}(s)}{\sigma_{x,z} (\sigma_x + \sigma_z)} ds$$

$$= \frac{120 I e}{8\pi m c^2 \beta^2} \bar{\gamma} \int \frac{\beta(s)}{\sigma^2(s)} ds$$

or

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$$\Delta\nu = \frac{120 I e}{4\pi m c^2 \beta^2} \frac{\bar{\eta}}{\epsilon} 2\pi R$$

with

$$\epsilon = \frac{20^2}{\beta} = 0.06 \text{ mm-mrad}$$

$$R = 610.2 \text{ m}$$

$$\gamma = 100$$

$$mc^2 = 0.9383 \text{ GeV}$$

We get

$$\Delta\nu = 4.64 \bar{\eta}$$

If it is safe to keep $\Delta\nu \leq 0.0025$,
 therefore one requires

$$\boxed{\bar{\eta} \leq 0.0005}$$

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Removal of the Electrons

Electrons have a longitudinal drift.
After a time t they have travelled a distance

$$l = v_e t$$

where $v_e \approx 1 \times 10^7$ cm/sec

We assume that after this distance they are removed. We take

$$t = \eta \tau_e$$

$\tau_e = 1.21$ sec is the production time per proton

With $\eta = 0.0005$

$$l = \underline{\underline{6,050 \text{ m}}}$$

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Drift in a Dipole (B_2)

This occurs at velocity v_D

$$v_D = \frac{E_x}{B_2} \cdot \frac{\omega_L^2}{\omega_L^2 + \omega_x^2} = \propto \frac{\omega_L \omega_x^2}{\omega_L^2 + \omega_x^2}$$

$$\omega_L = \frac{e B_2}{m_e}, \text{ } 2\pi \times \text{Larmor frequency}$$

$$= 5.6 \times 10^{11} \text{ Hz}$$

Therefore $\omega_L \gg \omega_x$, and

$$v_D = \propto \frac{\omega_x^2}{\omega_L} = 3.5 \times 10^5 \text{ cm/sec}$$

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Draft in a Quadrupole with Gradient B'

$$V_Q = \sigma \frac{\omega_Q \omega_x^2}{\omega_Q^2 + \omega_x^2}$$

where

$$\omega_Q^2 = \frac{1}{2} \left(\frac{e B'}{mc} \right)^2 \sigma^2$$

with $B' = 550 \text{ kG/m}$ and $\sigma = 4 \text{ mm}$.

$$\omega_Q = 2.9 \times 10^{10} \text{ Hz}$$

Therefore $\omega_Q \gg \omega_x$ and

$$V_Q = \sigma \frac{\omega_x^2}{\omega_Q} = 6.8 \times 10^6 \text{ cm/sec.}$$

In conclusion the drift velocity is quite smaller in the dipoles. The calculations of page 7 to clear the electrons have to be repeated by taking

$$v_d = v_e \approx 3.5 \times 10^5 \text{ cm/sec}$$

We obtain then

$$l = 212 \text{ m}$$

This corresponds to the length traversed in the dipoles: it is about 10 dipoles, that is 5 cells.

Solution: install pairs of cleaning electrodes in the warm sections at the beginning and at the end of each long straight section.

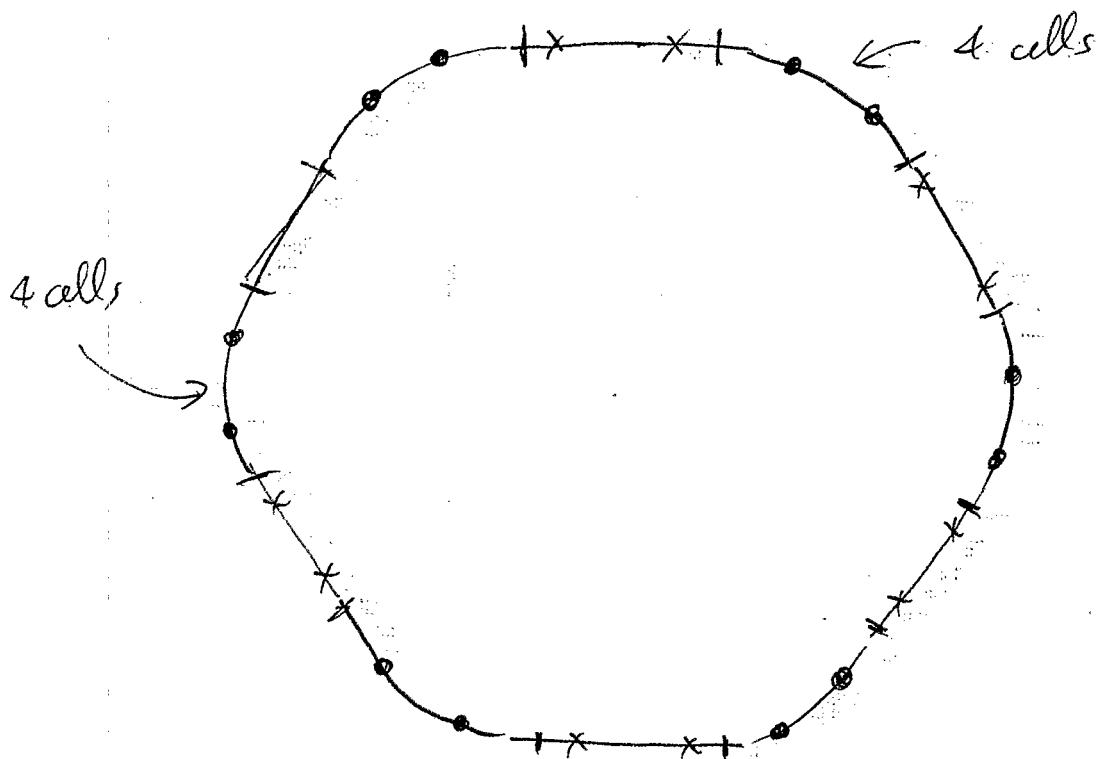
Install also pairs of cleaning electrodes in the arcs equally spaced 4 full cells apart. So there are in total 24 pairs, 12 in cold sections and 12 in warm sections (see figure next page).

Take a gap separation d flush with the vacuum chamber and ~~the~~ a length $L = d$.

To sweep the electrons away the following voltage is required

$$V_c = mc^2 \left(\frac{dV_e}{cL} \right)^2$$

which is quite negligible compared to $\Delta V = 43$ Volt.
It is quite safe to take $V_c \approx 100$ Volt.



- Cleaning Electrodes in cold section

- X " " in warm section